WorldView-2 data simulation and analysis results

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ABSTRACT

The WorldView-2 sensor, to be launched mid-2009, will have 8 MSI bands - 4 standard MSI spectral channels and an additional 4 non-traditional bands. Hyperspectral data from the AURORA sensor (from the former Advanced Power Technologies, Inc. (APTI)) was used to simulate the spectral response of the WorldView-2 Sensor and DigitalGlobe's 4-band QuickBird system. A bandpass filter method was used to simulate the spectral response of the sensors. The resulting simulated images were analyzed to determine possible uses of the additional bands available with the WorldView-2 sensor. Particular attention is given to littoral (shallow water) applications. The overall classification accuracy for the simulated QuickBird scene was 89%, and 94% for the simulated WorldView-2 scene.

Keywords: WorldView-2, QuickBird, AURORA (APTI), simulation

1. BACKGROUND

DigitalGlobe's WorldView-2 satellite, built by Ball Aerospace & Technologies Corp., is set to be launched from Vandenberg Air Force Base during the third quarter of 2009. It is a new and improved sequel to the WorldView-1 sensor, which was launched in September of 2007. Its most interesting aspect, in terms of research to come, is the 8-band spectral sensor; in addition to the traditional MSI panchromatic, Blue, Green, Red and Near Infrared (NIR) bands, the WorldView-2 sensor will have four new sensor band colors. There is a shorter wavelength blue band (Coastal), which peaks around 425 nm and is expected to be useful for water color studies. The Yellow band is centered at approximately 605 nm. The Red Edge band peaks near 725 nm, strategically placed at the onset of the high reflectivity portion of vegetation response. The longer wavelength Near Infrared band (NIR2) is sensitive to atmospheric water vapor and is centered around 950 nm[1]. The MSI spatial resolution is expected to be as sharp as 1.8 meters, with a panchromatic spatial resolution of 0.5 meters[2].

2. METHODS

The AURORA system was a hyperspectral sensor with 75 bands ranging from 352 nm to 1072 nm. This system was chosen because of its high Signal-to-Noise Ratio in the blue region and high spatial resolution. A bandpass filter method was used to simulate the image according to the approximate spectral response of the QuickBird and WorldView-2 sensors.

An AURORA image of Kaunakakai (on the island of Maui) in Hawai'i from June 13, 2000 was used as the basis for the simulation. This image was chosen because it included both urban areas and ocean environments that ranged in depth, providing a better sense of which spectral bands would be useful for analyzing specific types of environments.

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14. ABSTRACT
The WorldView-2 sensor, to be launched mid-2009, will have 8 MSI bands - 4 standard MSI spectral channels and an additional 4 non-traditional bands. Hyperspectral data from the AURORA sensor (from the former Advanced Power Technologies, Inc. (APTI)) was used to simulate the spectral response of the WorldView-2 Sensor and DigitalGlobe's 4- band QuickBird system. A bandpass filter method was used to simulate the spectral response of the sensors. The resulting simulated images were analyzed to determine possible uses of the additional bands available with the WorldView-2 sensor. Particular attention is given to littoral (shallow water) applications. The overall classification accuracy for the simulated QuickBird scene was 89%, and 94% for the simulated WorldView-2 scene.

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Figure 1. The AURORA (APTI) image of Kaunakakai (on the island of Maui) in Hawai'i from June 13, 2000.

Table 1. Spectral channel information for the QuickBird and WorldView-2 Sensors, and APTI bands used to create the simulated images[1,3].

QuickBird		
Spectral Band	Spectral Band Edges (nm)	APTI Bands used in Simulation (nm)
Pan	515 – 875	518 – 877
Blue	450 – 510	450 – 508
Green	500 – 590	498 – 586
Red	620 – 685	624 – 683
NIR	755 – 865	751 – 867

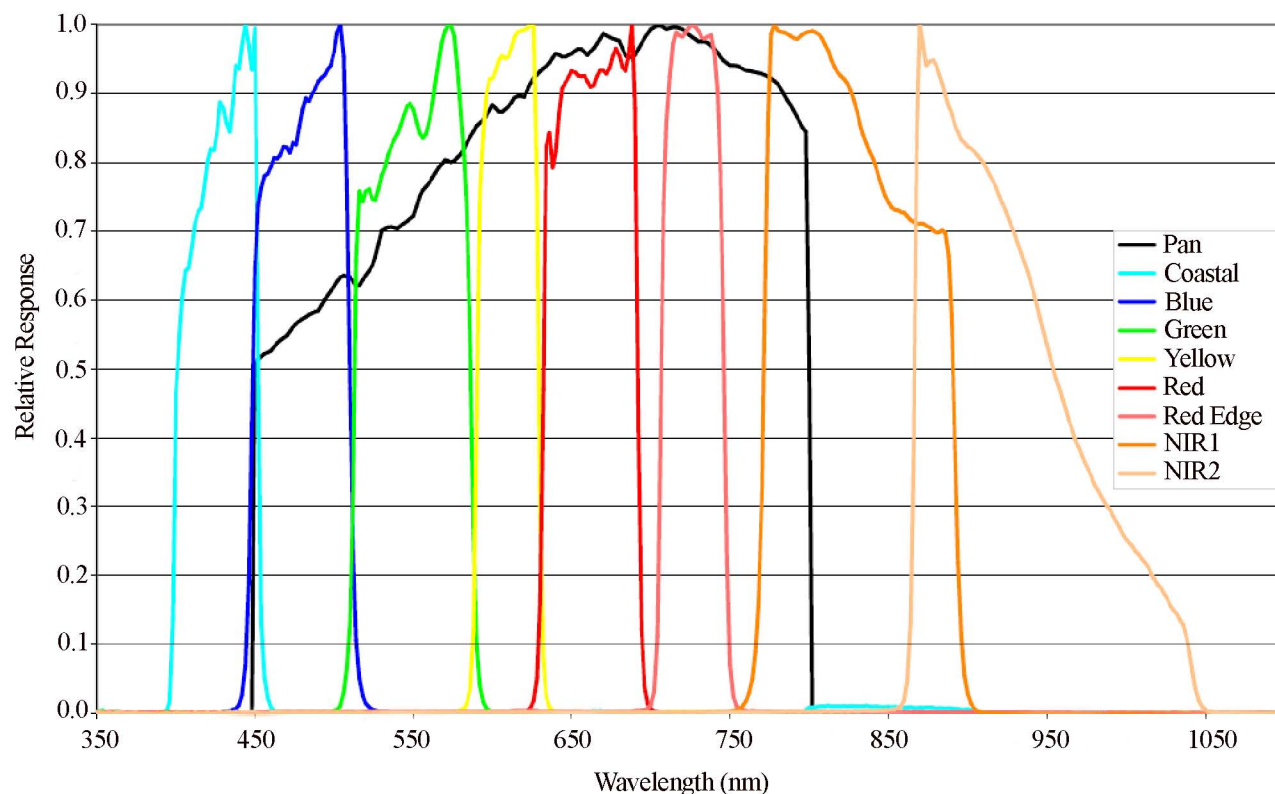| WorldView-2		
Spectral Band	Spectral Band Edges (nm)	APTI Bands used in Simulation (nm)
Pan	450 – 800	450 – 799
MS1 – NIR1	770 – 895	770 – 897
MS2 – Red	630 – 690	634 – 692
MS3 – Green	510 – 580	508 – 576
MS4 – Blue	450 – 510	450 – 508
MS5 – Red Edge	705 – 745	702 – 741
MS6 – Yellow	585 – 625	586 – 624
MS7 – Coastal	400 – 450	401 – 450
MS8 – NIR2	860 – 1040	858 – 1042

Figure 2. Spectral response of the WorldView-2 Sensor[1]. (for color image please see electronic version)

2.1 Supervised classification

Training sites were drawn by hand, using visual interpretation of the APTI image and Google Earth. These training sites were used to generate a supervised classification result of the APTI image. The training sites are shown in Figure 3.

After experimenting with five different types of supervised classifications, it was determined that the Spectral Angle Mapper (SAM) Classification was the most accurate for the purpose of this paper. The SAM Classification algorithm 'determines the spectral similarity between two spectra by calculating the angle between the spectra and treating them as vectors in a space with dimensionality equal to the number of bands.'[4]

The APTI image and the simulated QuickBird and WorldView-2 images were classified using the same training sites. All spectral bands were used to create the classification results.

2.2 Confusion matrices

Using the APTI SAM Classification result as 'truth,' confusion matrices were then created for the simulated scenes. They showed an overall accuracy of 89% for the QuickBird simulation and 94% accuracy for the WorldView-2 simulation. The additional bands available on the WorldView-2 sensor seem to provide a significant improvement in classification ability.

2.3 Mapping accuracy

An attempt was made to determine specific cases where the additional WorldView-2 spectral bands provide a significant improvement in classification results. The 'Mapping Accuracy,' as defined in the Remote Sensing Tutorial by Dr. Nicholas M. Short, was calculated for each class by dividing the number of correctly classified pixels by the total of correctly classified pixels and errors of commission and omission[6].

The mapping accuracy varied significantly over the range of classes. The most significant improvement in mapping accuracy was found in the 'Mountain 3' class.
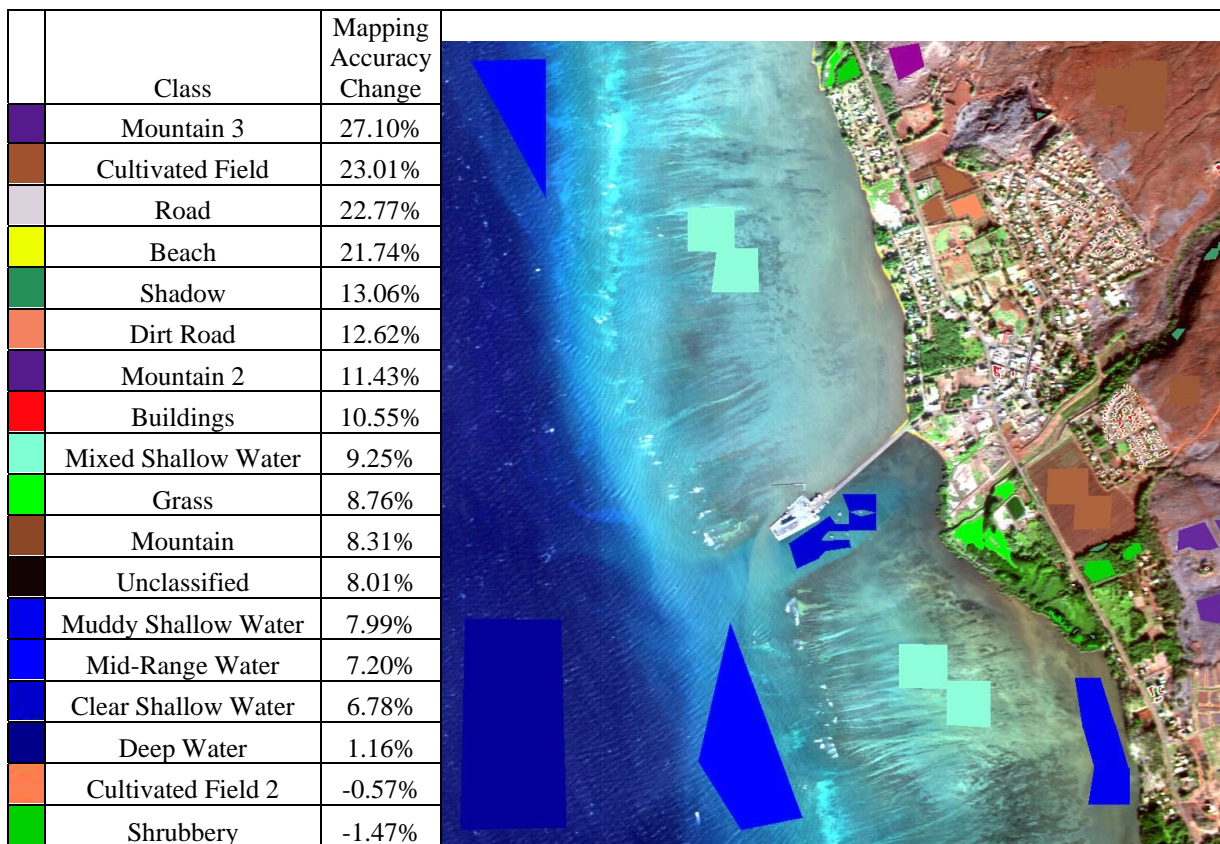
	Class	Mapping Accuracy Change	
	Mountain 3	27.10%	
	Cultivated Field	23.01%	
	Road	22.77%	
	Beach	21.74%	
	Shadow	13.06%	
	Dirt Road	12.62%	
	Mountain 2	11.43%	
	Buildings	10.55%	
	Mixed Shallow Water	9.25%	
	Grass	8.76%	
	Mountain	8.31%	
	Unclassified	8.01%	
	Muddy Shallow Water	7.99%	
	Mid-Range Water	7.20%	
	Clear Shallow Water	6.78%	
	Deep Water	1.16%	
	Cultivated Field 2	-0.57%	
	Shrubbery	-1.47%	

Figure 3. The AURORA (APTI) image showing the ROIs used as training classes for the Spectral Angle Mapper, and the difference in mapping accuracy between WorldView-2 and QuickBird. (for color image please see electronic version)

2.4 Band sensitivity analysis

There is a significant improvement in the overall accuracy of the classification results when using the additional WorldView-2 spectral bands. The next step was to determine, for a given class, which of the spectral bands has the most impact on the classification. Sections 2.4.1-2.4.3 describe the different methods used to determine the band sensitivity.

2.4.1 Spectral profiles

A visual inspection of the mean spectra of the classes with the greatest improvement in mapping accuracies did not yield any obvious clues as to which, if any, of the new WorldView-2 bands is most important. These spectra are illustrated in Figures 4a-c.
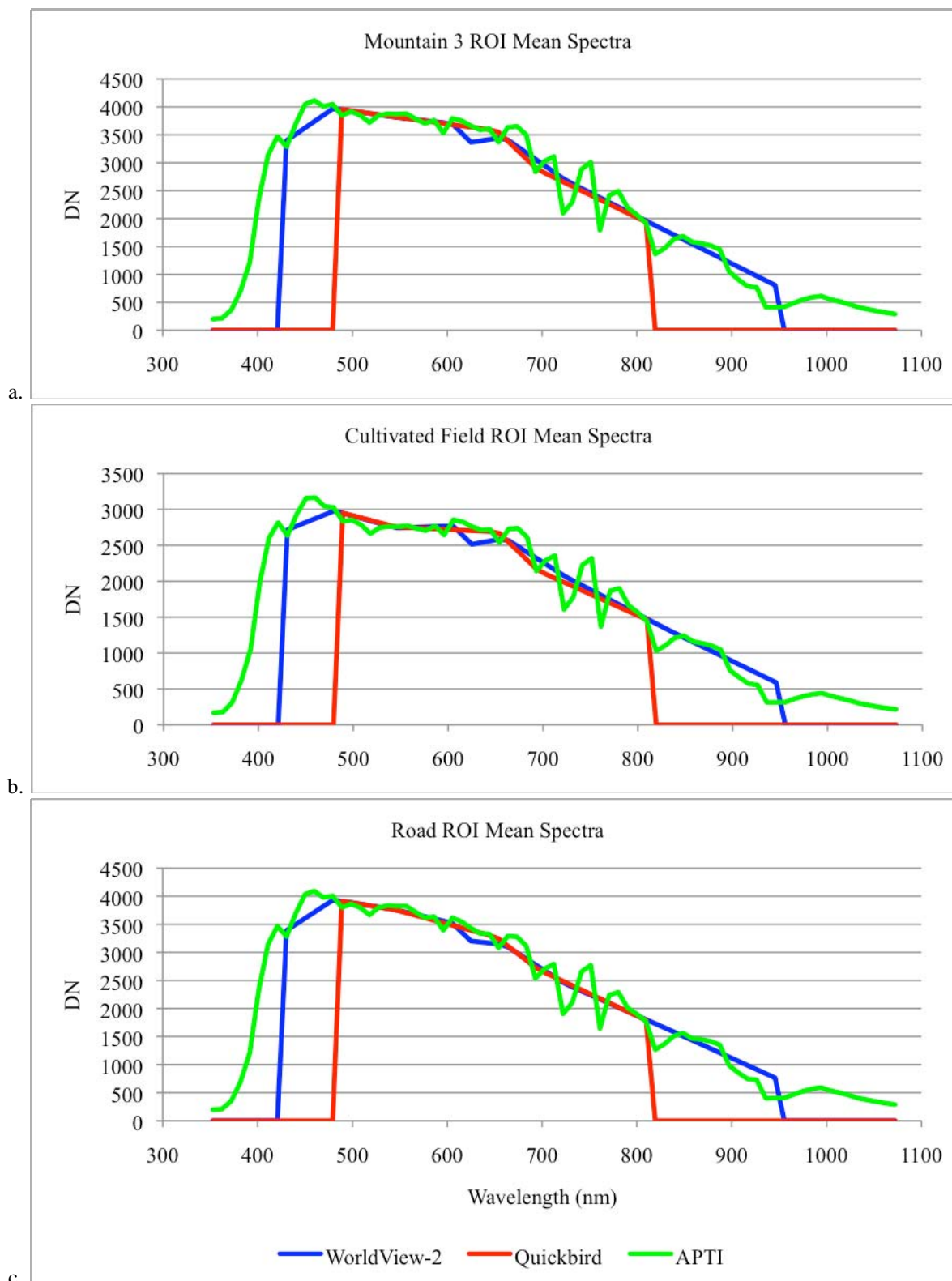
Figures 4a, b, and c. Mean spectra from the APTI scene, WorldView-2 simulated scene, and QuickBird simulated scene for three ROIs. (for color image please see electronic version)

2.4.2 Mapping accuracies using combinations of bands

Image band combinations of the four original bands (Red, Blue, Green, and NIR1) and one additional new band were classified using the original training classes. Peaks in the curves are representative of improvments in mapping accuracy. This highlights which bands have the most effect on the classifiation results for each class.

Three graphs were created to highlight changes in mapping accuracy for categories of classes. One such graph looked at the water classes (Figure 5). Deep and Mid-Range Water both had spikes when the Coastal band (MS7) was added, and Mixed and Muddy Shallow Water showed improvement with the addition of the Red Edge band (MS5), as well as the Coastal band (MS7). Clear Shallow Water showed the best results with the added NIR2 band (MS8). Interestingly, all of the water classes have noticeable drops in accuracy when the Yellow band (MS6) is added.
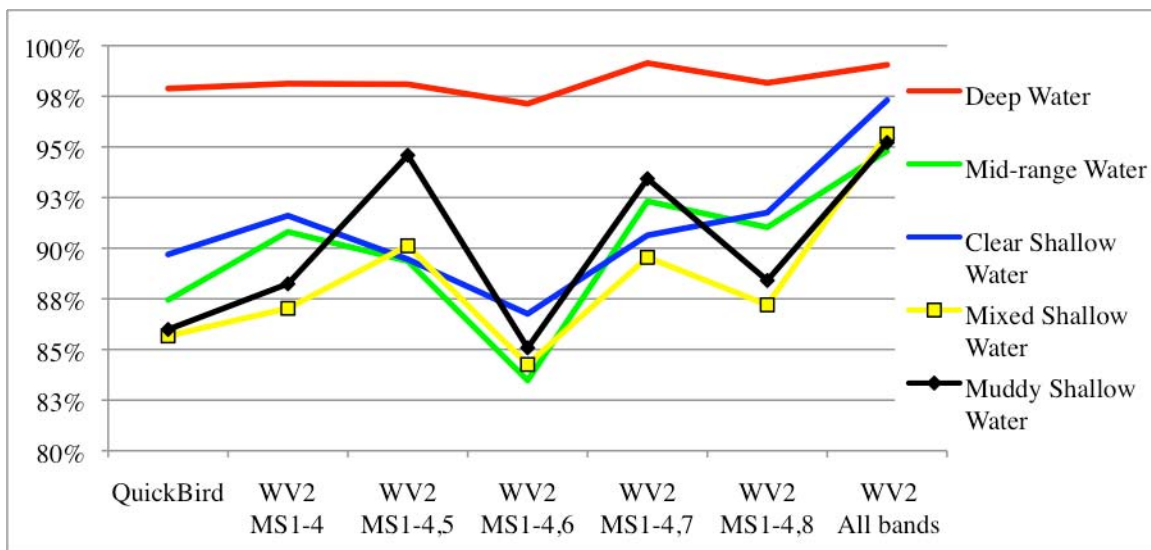

Figure 5. Mapping accuracies for the water classes. (for color image please see electronic version)

Figure 6 focuses on the land classes. The Beach class was more accurate with the addition of the NIR2 band (MS8) (like the Clear Shallow Water class), although the Beach pixels that were specifically chosen for the training class were not underwater. The majority of the other darker, dry land classes (Mountain classes, Road and Cultivated Field) were all found to be most accurate when the Coastal band (MS7) was added. The Dirt Road class showed a slight improvement with the addition of the Yellow band (MS6), and Buildings were also slightly improved when the NIR2 (MS8) and Yellow (MS6) bands were added.
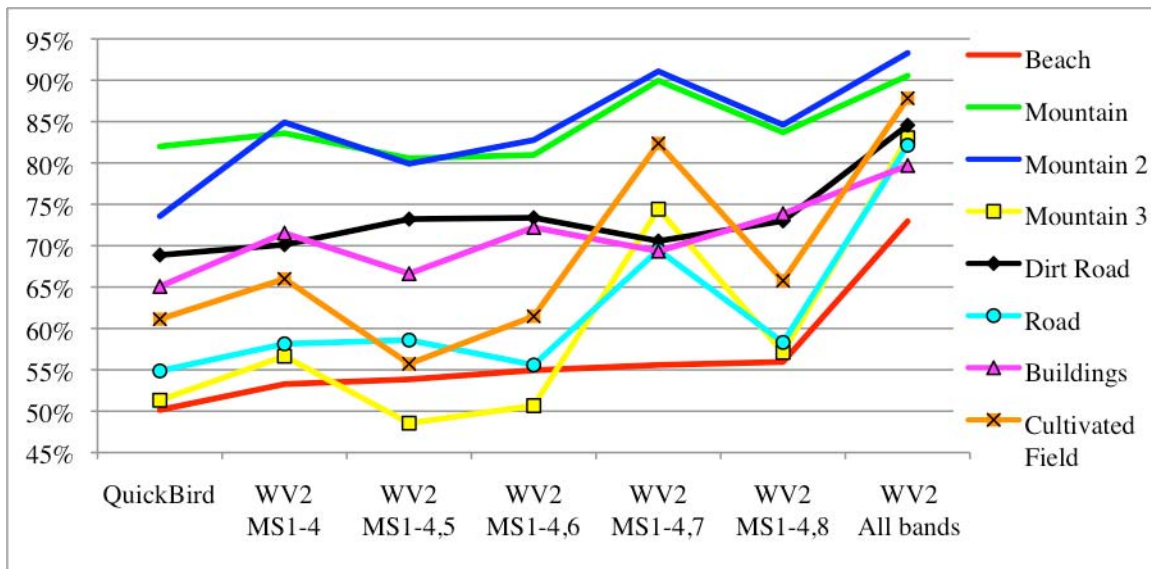
Figure 6. Mapping accuracies for classes containing land without significant vegetation. (for color image see electronic version)

Visual inspection of the image does not indicate any live vegetation in the areas chosen as Cultivated Field. However, since residual vegetation might have been unintentionally included in the training class, it is included in Figure 7 as one of the vegetative classes. The Cultivated Field class does, in fact, behave more like the land classes in Figure 6. All other classes that have vegetative areas, including Cultivated Field 2, Grass and Shrubbery, were most accurate with the addition of the Red Edge band (MS5). Shadowed areas were accurate when NIR2 (MS8) was added. It is interesting to note that for the Shrubbery class, the best mapping accuracy is achieved by using the combination of bands MS1-4 and 5. The result using this 5-band combination is even better than the classification using all 8 spectral channels. For the other classes containing vegetation (Cultivated Field 2 and Grass), the result using bands MS1-4 and 5 is virtually the same as the result using all 8 bands.
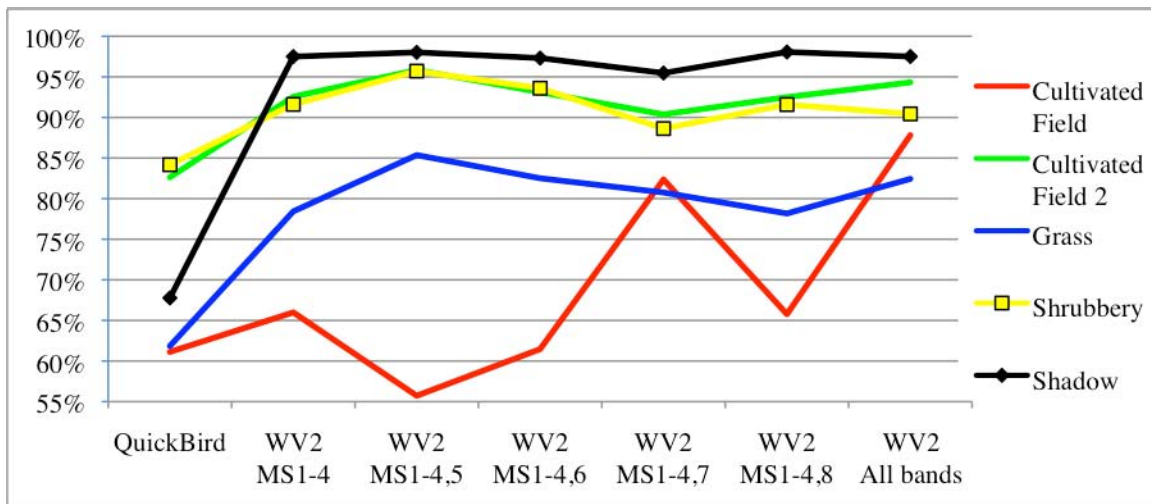

Figure 7. Mapping accuracies for classes containing vegetation, and the Cultivated Field class. (for color image see electronic version)

All classes show significant improvement when transitioning from QuickBird to WorldView-2 with all eight of its bands. There was even an improvement over the QuickBird results using only the four original bands from the WorldView-2 simulation. This was unexpected because the four traditional bands (RGB, NIR) vary only slightly between the two sensors. (See Table 1 above for the sensor specifications).

2.4.3 Spectral separability

The final method used to understand the impact of specific WorldView-2 bands was a measure of spectral separability. The spectral separability tool in ENVI, as measured by the Jeffries-Matusita and Transformed Divergence methods, yields values that range from 0 to 2.0. A value above 1.9 indicates good separability, and any other value below 1.9 has low separability[5].

It was assumed that the spectral separability of classes would increase with the addition of spectral information. To test this assumption, ROIs were created for each of the SAM classes of the APTI image. The APTI classification result, using all 75 spectral bands, was assumed to be the 'correct' result. The separability of these ROIs was calculated for the APTI image, the WorldView-2 image, and the QuickBird image. The assumption that additional spectral information would yield a higher measure of separability between the classes held. The APTI bands gave the greatest separability between classes, and the QuickBird bands gave the least separability. The WorldView-2 result was in between the two extremes.

Following these results, it was further assumed that the relative importance of each WorldView-2 band could be inferred by measuring the spectral similarity of the classes of the original four bands, plus one of the new bands. The spectral separability was calculated on multiple spectral subsets where, in each case, one of the new WorldView-2 bands was added to the original four spectral bands (Red, Green, Blue, NIR1). Unfortunately, there was no clear-cut result showing that any particular WorldView-2 band was more important than another.

The spectral separability for the 'Mountain 3' class is shown below. Since the greatest improvement in mapping accuracy was found in the Mountain 3 class, it was expected that this class would best demonstrate the affect of adding a WorldView-2 spectral band. Using the SAM classifier, the Mountain 3 class was most often confused with pixels from the Beach, Road, Cultivated Field, Buildings, Dirt Road, or Mountain classes. While there is a definite improvement in separability when all additional bands from the WorldView-2 sensor are included, it is not clear from this analysis which band is specifically responsible for the improvement over the QuickBird result.
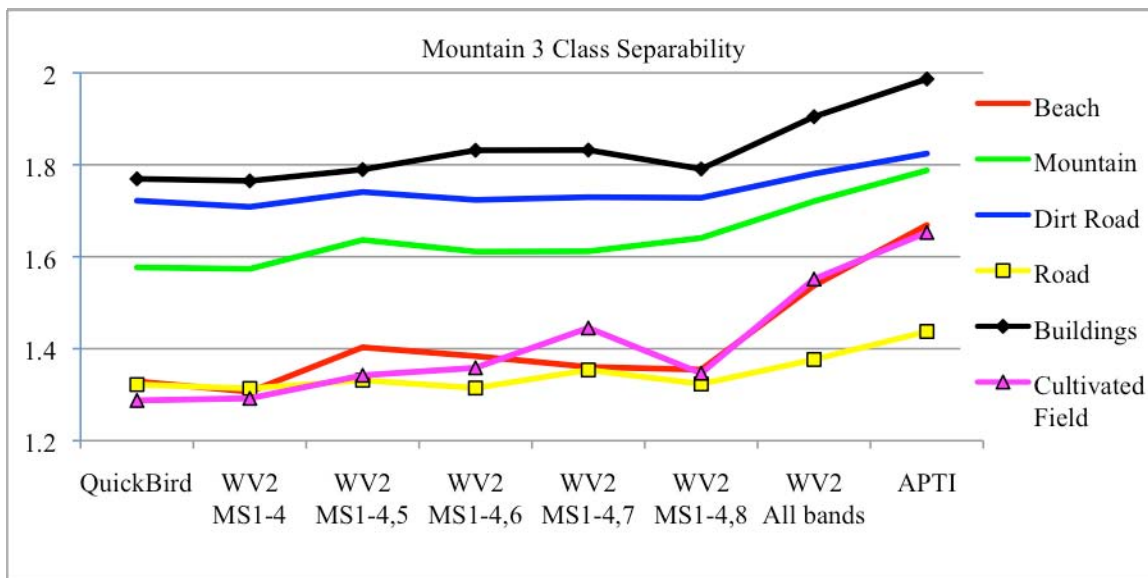

Figure 8. Jeffries-Matusita separability measures between Mountain 3 class and Beach, Road, Cultivated Field, Buildings, Dirt Road, and Mountain classes for combinations of bands. These are the classes which caused the most confusion in the SAM classification result. 'WV2, MS1-4,#' refers to the simulated WorldView-2 bands used in the separability measurement. (for color image please see electronic version)

3. CONCLUSIONS

A hyperspectal image from the APTI AURORA sensor was used to create a simulated 8-band WorldView-2 image and a 4-band QuickBird image. Training class ROIs were drawn by hand and used to classify the images with a SAM classifier. The SAM result for the APTI image was accepted as 'truth'. The mapping accuracy of the simulated scenes was measured against the APTI classification result. The WorldView-2 simulation gave a significant improvement in mapping accuracy for most classes over the QuickBird result.

Multiple methods were used to attempt to quantify the importance of particular WorldView-2 bands for image classification. A visual inspection of the spectra did not provide any clues, and the analysis of spectral separability was also inconclusive. The classification confusion matrices for combinations of WorldView-2 bands, however, showed that certain bands affect the classification accuracy for different land cover types. The Coastal and Red Edge bands are useful for more accurately classifying water. The Coastal band also significantly improves the mapping accuracy of non-vegetative land regions. For areas with photosynthesizing vegetation, the Red Edge band provides the most significant improvement in classification accuracy.

There are multiple possible sources of error in this analysis due to the simplicity of the simulation. For one, the bandpass filter method does not take into account the particular spectral filter function of each of the sensors. Secondly, the classification of the Aurora image which was taken as 'truth' was dependent upon training classes which were drawn by hand, with no in situ ground truth measurements taken. Even with these possible errors, the degree of improvement in mapping accuracy for the WorldView-2 classification is significant. Once WorldView-2 is launched and imagery has been returned, it will be interesting to analyze real imagery and compare results to those acquired in this experiment.

REFERENCES

[1] "WV1_WV2_SpectralResponse". 2008. DigitalGlobe. Downloaded on 8 Oct. 2008 from
<http://www.digitalglobe.com/downloads/WV1_WV2_SpectralResponse.pdf>.
[2] "WORLDVIEW-2". 2008. Ball Aerospace & Technologies Corp. Downloaded on 23 Oct. 2008 from
<http://www.ballaerospace.com/page.jsp?page=82>.
[3] "Spectral Filter Function". Released 27 Feb. 2002 by DigitalGlobe.
[4] Kruse, F. A., A. B. Lefkoff, J. B. Boardman, K. B. Heidebrecht, A. T. Shapiro, P. J. Barloon, and A. F. H. Goetz, 1993, "The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging spectrometer Data." Remote Sensing of the Environment, v. 44, p. 145 – 163.
[5] Richards, J.A., 1999, Remote Sensing Digital Image Analysis, Springer-Verlag, Berlin, p. 240.
[6] Short, N. M. "The Remote Sensing Tutorial." NASA. Downloaded 25 Feb. 2009 from <http://rst.gsfc.nasa.gov/>.